Solar Program Annual Review Meeting

Session: CIGS
Company: GE Global Research
Funding Opportunity: TPP
Title: A Value Chain Partnership for PV Industry Growth

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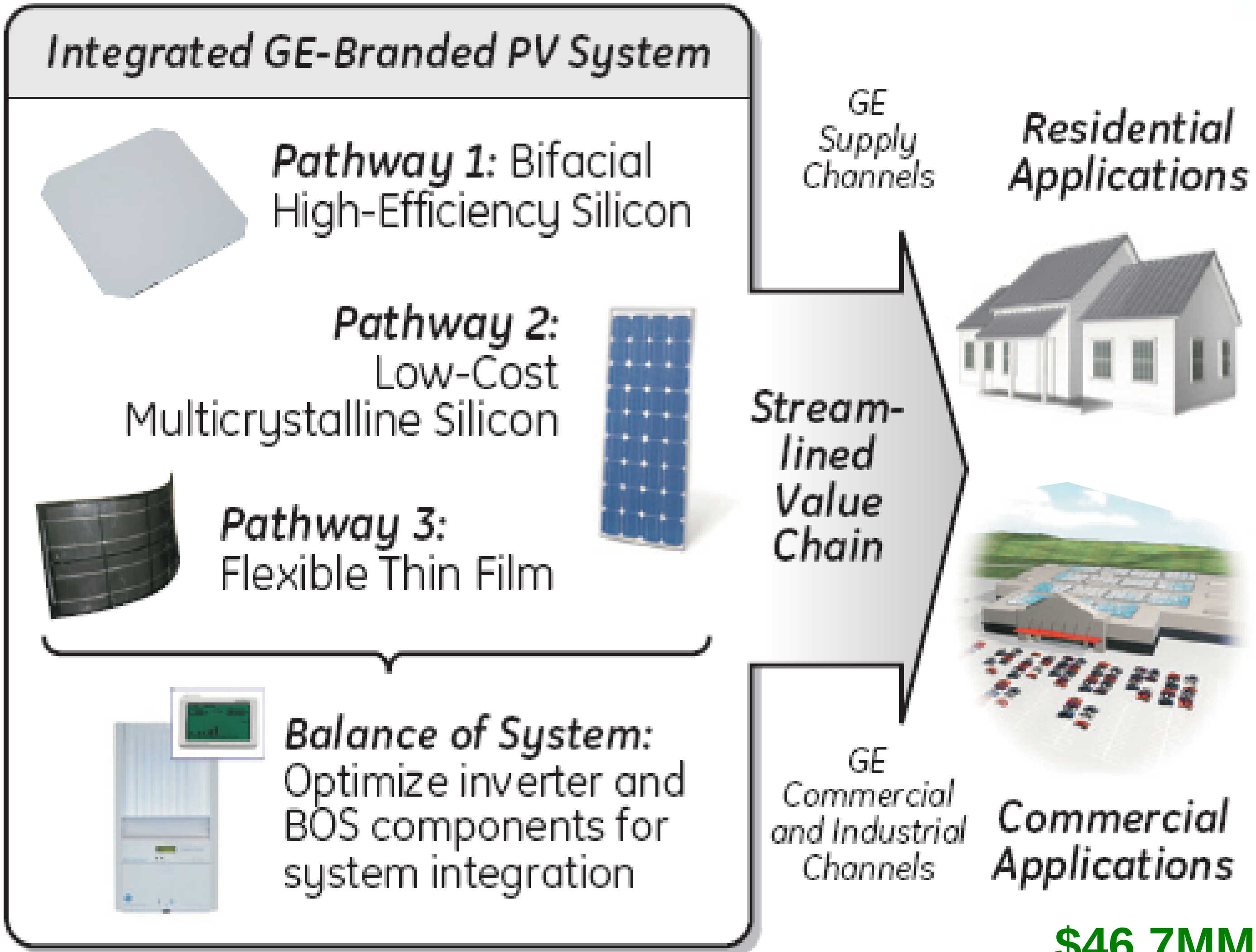
Overall Program Scope



$46.7MM Effort
over 3 years

Budget and Roadmap Alignment

Flexible TF Goal: Develop low-cost, reliable flexible encapsulation strategy including moisture barrier coating technology on weatherable polymers.

Thin Film Packaging Budget Overview

Budget Period 1	Budget Period 2	Budget Period 3	Total Budget
$1.5 M	$0.8 M	$0.6M	$3 M

Alignment to Roadmap Metrics

Qualification	Life	Degradation	Installed Cost	LCOE (2015)
IEC 6-1646	> 20 yrs	< 1%/yr	< $2.60/W	$0.06–$0.08

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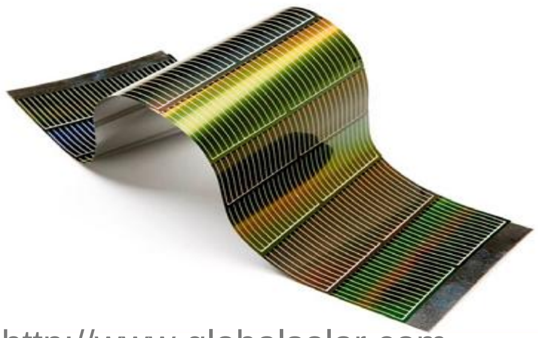
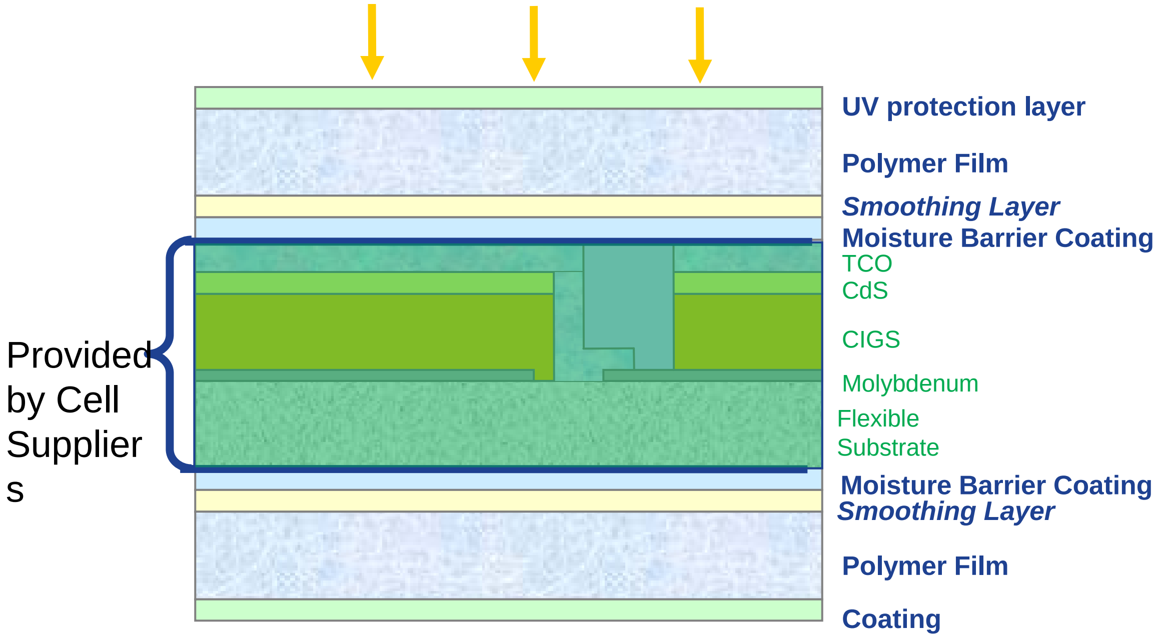
Project Overview

1. Validate performance of CIGS cells on flexible substrates - Vendor relationships
2. Develop UV-stable polymer film, barrier coating, and encapsulant
3. Develop interconnect and power-off method
4. Produce prototype module capable of passing certification tests

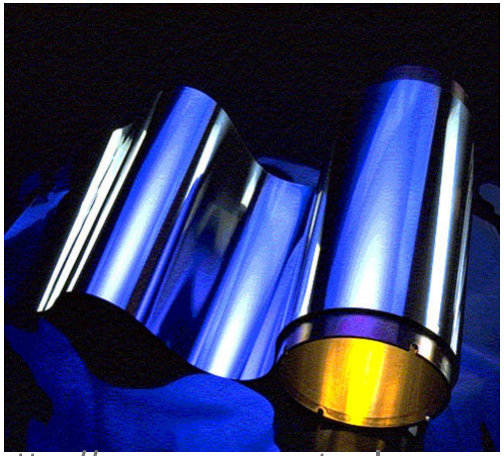


http://www.globalsolar.com



GE Barrier Coating Technology

GE UV-Stabilization of Polymers



http://www.ascentsolar.com

Vendor R2R CIGS Technology

Ultimate Goal: Cost-Effective R2R Thin Film Photovoltaics

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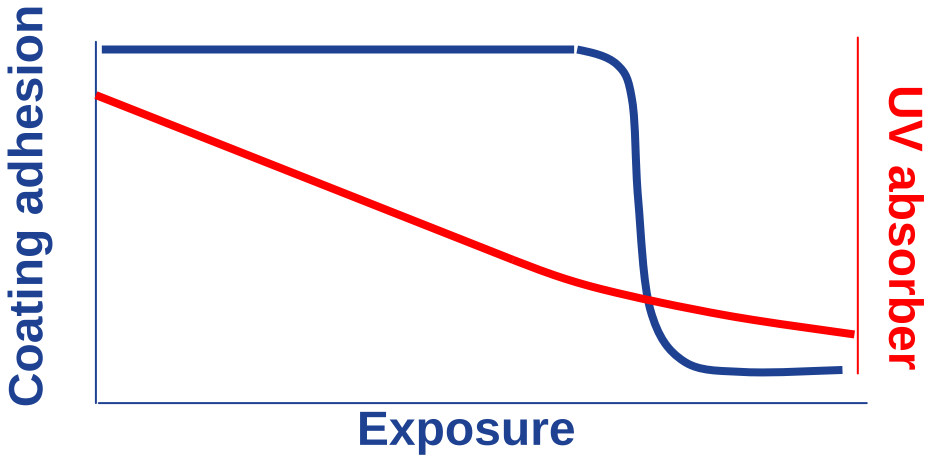
Critical Success Factors and Risks

Critical Success Factor	Risk
Cell availability	Cell suppliers unable to provide required number of cells
Cell efficiency	Cell efficiencies too low to allow detectible variations in test results (signal/noise ratio)
Cell consistency	Inconsistent cell efficiency and other performance characteristics conflicts with weathering and barrier coating results
Moisture permeation rate	Moisture penetration detrimental to cell performance
Reliable packaging	**Photo-induced degradation** of polymer films **Delamination** due to poor adhesion of encapsulants
Flexible packaging	Weatherable polymers or moisture barriers not resistant to mechanical flexibility
Packaging cost	High cost of base films and/or functional coatings
Cell interconnect technology	Unable to interconnect cells without thermal damage

Methodology of TF PV Packaging

- Protect the device – mechanical, insulation, moisture
- Flexible packaging – must protect the package – UV, moisture
- Device + package must be cost-effective – challenging

- Need to predict lifetime
  – accelerated testing protocols needed
- Need to pass certification tests
  – may or may not relate to lifetime



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Accelerated Testing

Determine Failure Mechanisms

↓

Stresses

↓

Measure performance at various stress levels

↓

Fit to degradation model

(Arrhenius activation energy)

Make sure acceleration does not change mechanism!!!

Account for interactions

↓

Determine acceleration factors (ratio)

↓

Test at accelerated conditions

↓

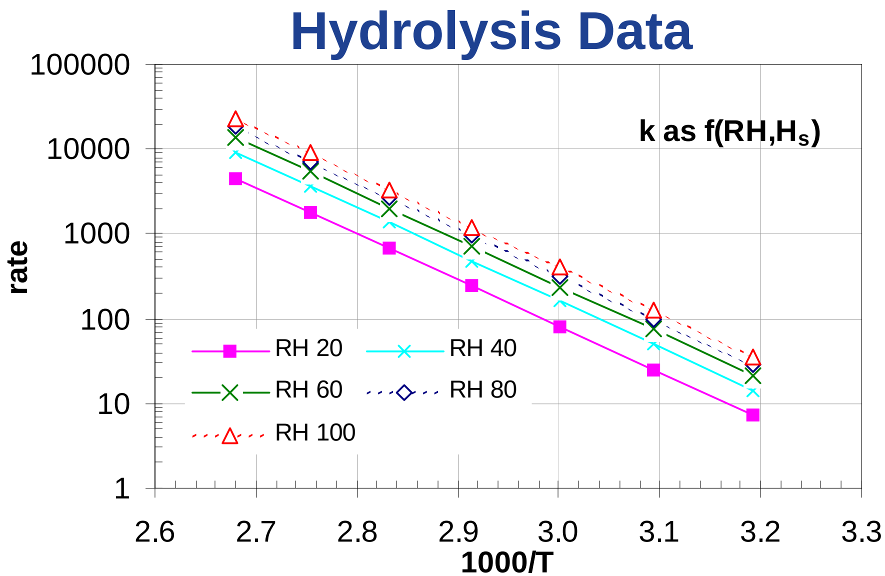
Predict life

Accelerated Testing Example – Polymer Weathering

Determine Failure Mechanisms – photo-oxidation, hydrolysis

Stresses – UV dose, temperature, moisture, thermal cycle

Measure performance at various stress levels



Fit to degradation model

Degradation rate = function(stress values)

Input any stress profile (weatherometer, Miami, Phoenix) --> calculate rate of degradation

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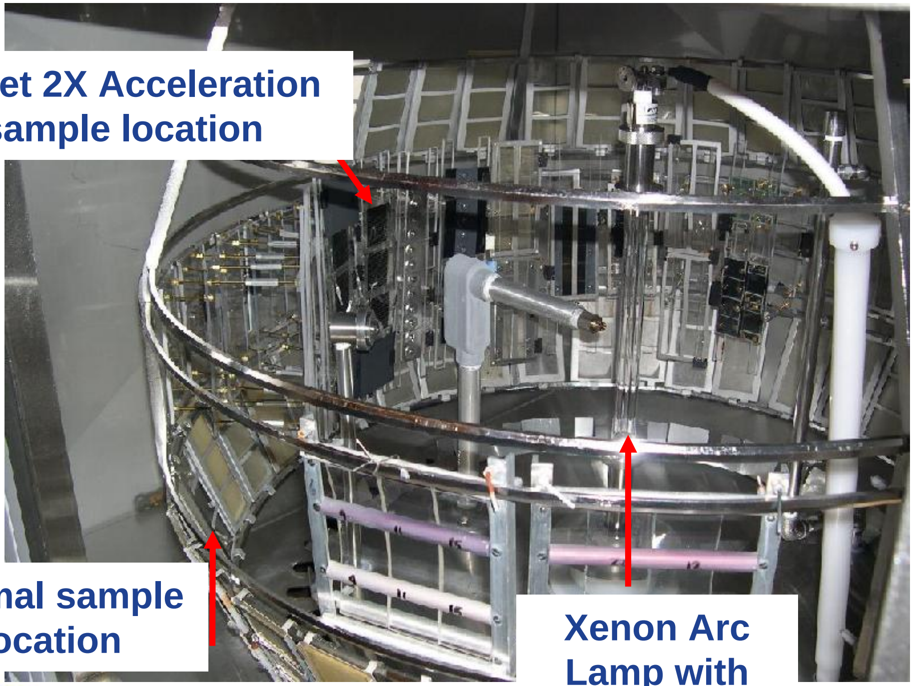
Determine acceleration factors

- Weatherometer: 1 “day” compressed into 3 hours test
  - Accelerate photo-oxidation about 7-8× Phoenix
  - Accelerate hydrolysis about 7-8× Miami
- Move samples closer to lamp (“offset”) – light, temp → 2X
  - 14 × means <u>*2 years weatherometer*</u> ~ 28 years outdoor

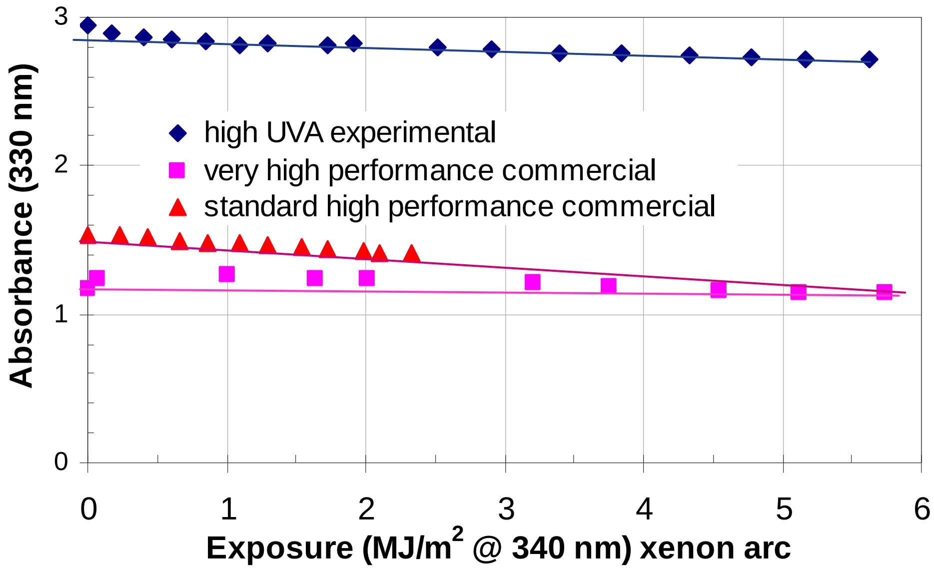


Test at accelerated conditions

Predict life

Project Update: Results- *Polymer Film*

- 3 stabilization schemes identified for PC and PET (lower cost, recyclable alternatives)



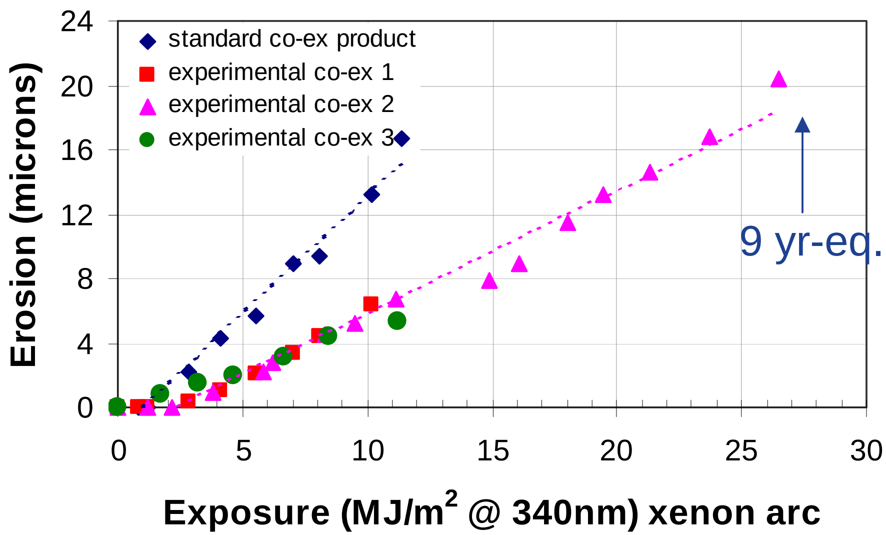
Coatings

Lifetime is determined by stability of UV absorbers (k), initial transmission T_o, and sensitivity of substrate (D_{fail}).

$$t_{fail} = \frac{1}{k}\log_{10}\left[\frac{10^{kD_{fail}} + T_0 - 1}{T_0}\right]$$

Co-extruded highly stabilized polymer layers

need low erosion rate



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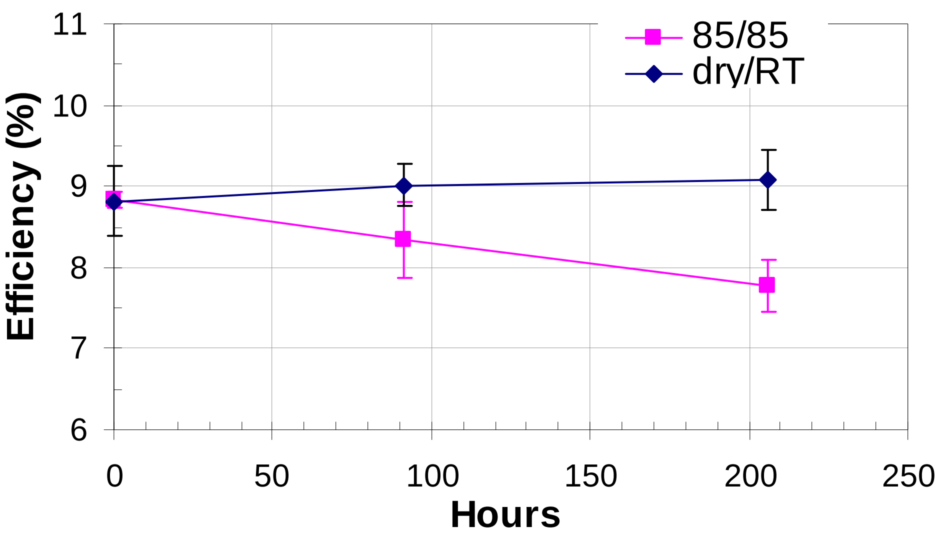
Project Update: Results- *Moisture Barrier*

Simultaneous testing at multiple humidities and temperatures

- Constant relative humidity at approx. 83, 75, 50, 25, and 0%
- Temperatures of 85, 75, 65, and 55°C
- Cells coated with thin PMMA layer to prevent liquid water or salts from actually contacting the surface
- 280 hours of exposure so far

Damp Heat Test:

Cells mounted such that only moisture ingress through the front is a factor



Results Overview

- Cells specified, received from vendors
- Cells validated quoted performance of adequate efficiency
- Three UV-stabilization approaches identified
- Accelerated weathering conditions have been determined
- Samples have accumulated 5-8 years accelerated testing at 7X and 14X acceleration factors
- Ramping up additional barrier and lamination experiments.